SEMI ANNUAL PROGRAM REPORT

ON

THE EFFECTS OF MAGNETIC NOZZLE CONFIGURATIONS ON PLASMA THRUSTERS

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PROJECT ABSTRACT

MPD arc devices have been operated at power levels from 10 KW to 0.1 MW. When these devices have magnetic fields applied to them, they show marked increases in thrust in direct proportion to the magnitude of the applied field. Electrode erosion may be influenced by applied fields. This proposal will study the application of variable magnetic fields over a range of thruster powers, gas densities, and thruster configurations. We propose to examine this behavior with numerical codes and limited but relevant experimental tests.

SCHEDULE OF WORK

First Year

Theory:

1) Reactivate computer code to predict plasma behavior in magnetic nozzle and re-confirm previous studies.

2) Begin detailed study of flow behavior with code by altering transport properties and source conditions.

Experiment:

1) Design, fabricate, and test discharge device to generate electrical discharge and gas feed appropriate for Arc/MPD study. Design and test magnetic nozzle circuitry and coils.

2) Conduct initial tests with diagnostics in the exhaust.

PROJECT ACTIVITY

Theory:

Previous research carried out by the principal investigator and his students had resulted in the development of a number of computer programs. These programs are capable of predicting important component parts of codes that are needed in the present effort. Specifically, magnetic fields generated by electrical current configurations, the convection diffusion, and energy exchange occuring in plasma generated by MPD and other sources are modeled. At this point in time, these codes have been reactivated and have been established in active operation on Ohio State University computers.

At the present time, test runs are being made to establish the correctness and integrity of these previously developed codes. Further, following a number of meetings with NASA Lewis Staff, the method of communicating computed results between NASA Lewis and Ohio State via TELENET has been established. Plans have been laid for specific collaborative works in the next few months.

This effort is being carried out primarily by P. Mikkeledes, a Research Associate at OSU, who is working half time during Summer Quarter.

Experiment:

As is normal, experimental work progresses more slowly than theoretical work. During this reporting period, a number of tasks have been accomplished; they are as follows:

1. Acquisition of a number of critical elements of the discharge apparatus from the Pennsylvania State University has been completed. These include: Two-Stage Vacuum Pump; 4" gate valve; 50 kV, 2A Power Supply; energy storage compactors that will allow 300-500 us discharges.

2. Design of a new concept plasma source. This involves new concept vacuum devices to suppress pressure buildup during the 300-500 us exhaust. It also involves a new concept source, with plasma generated by solid teflon or polyethylene ablation in the arc discharge. A new concept ballast resistor involving stainless steel sheet has also been designed. Design of discharge peripherals has also been completed.

3. Fabrication of capacitor racks and elaborate safety barriers has also been completed. Plexiglass plates one inch thick will shield the operator and three-quarter inch thick aluminum plates plastic will contain the energy storage units.

Design tasks were completed by Visiting Professor Peter Turchi, RDA, Alexandria, VA. Beginning Summer Quarter, a half-time Research Associate George Soulas is working in the laboratory. A part-time electrical/mechanical technician is carrying out the fabrication, assembly and testing of discharge components.

Diagnostic Initiative:

With the availability of DOD funds for laboratory development, a proposal was submitted on May 27, 1988 to ONR. The proposal was titled "Laser Diagnostics of Plasma Thruster" and would total $126,330, with 30% University matching of ($37,900).

This equipment request, if granted, will allow three new, high resolution diagnostic techniques to be developed for thruster plasmas: (1) multi-beam IR and FIR interferometry to determine electron densities; (2) Faraday rotation measurements of local magnetic fields; and (3) FIR measurements of density fluctuations which are indicative of anomalous transport.

The equipment that is being requested will utilize a CO_2 laser source which can operate CW or pulsed (at power levels five times larger). This long wavelength (10.6 um) radiation allows much more sensitive measurements to be made than can be accomplished with visible light. The laser will be coupled with a Far Infrared Laser System which is capable of generating laser beams from 70-500 um at tens of milliwatt power levels. There is a need for a considerable range of optical components such as gratings, mirrors, beam splitters, ite, as well as state-of-the-art detectors and signal recorders and data processing equipment.

Publication of Research Results:

A research paper titled "Acceleration of Plasma in Magnetic Nozzle Configurations" by T. M. York and B. A. Jacoby has been accepted for presentation at the 20th International Electric Propulsion Conference, October 3-6, 1988, in Garmaisch Partenkirchke, West Germany. An abstract is attached.

ABSTRACT

Acceleration of Plasma in Magnetic Nozzle Configurations
by

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Over the past twenty years, applied magnetic fields have been added to plasma thruster configurations with the hope of assisting and controlling the gas acceleration. In fact, dramatic improvement in thrust ($\sim B^2$) had been reported in 1973 with an MPD device. Yet to date, there has been no direct evidence presented of the local interactions that occur in such magnetic field configurations or what mechanisms may be active in such situations, i.e., the reality of a "magnetic nozzle" has never been demonstrated. This study will present the results of detailed measurements of plasma flowing through a magnetic expansion configuration, analysis of these data within existing theories, and finally, indicate the degree of correctness of existing notions.

The experiment was conducted with well-defined source plasma and magnetic field geometry generated in a pulsed theta-pinch discharge device. With a 40 mT ducterium gas fill in a 3.81 cm radius discharge tube, following pre-ionization an axial 23 kG magnetic field confined a plasma on axis with 10^{16} cm^{-3} and 20 eV properties. The radial magnetic field confinement resulted in a plasma which was distributed uniformly about the axis and flowed out the ends; a minimum area throat formed near the end of the theta coil and the diverging magnetic fields outside the coil formed a magnetic nozzle configuration within which the plasma acceleration was studied. The diagnostics employed in this experiment were Thomson scattering, continuum radiation spectroscopy, local magnetic field probes, local pressure probes, and diamagnetic loops. Axial temperature and density profiles were mapped from the coil into the magnetic nozzle region. A radial scan of temperature and density was made at various axial positions using Thomson scattering.

There was a positive identification of throat formation 6 cm inside the coil end. Outside the coil there was clear indication of nozzle effects, i.e., fields confining the plasma (Figure 1). The conversion of thermal energy to flow energy was observed in the axial temperature profile. Flow velocities both inside and outside the theta-pinch coil were mapped experimentally using the pressure probe and Thomson scattering (Figure 2), providing the first definitive measurement of flow velocities made in such a configuration (Figures 3,4).

Throat velocities are compatible with cusp speed and coincidentally with sound speed (Figure 3). Density variation was found to be compatible with simple isentropic expansion from the throat, but not from the source reservoir. Temperature variation did not agree with any simple expansion theory. A complex 2-D axisymmetric MHD code was used to model the flow and clearly, j x B interactions were evident. Generally, the flow is indicated to be nonisentropic and complex.

References

1. C. J. Michels and T. M. York, "Exhaust flow and propulsion characteristics of a pulsed MPD arc thruster", AIAA Journal, vol. 11, no. 5, pp. 579-580, May 1973 (AIAA Paper 72-500).

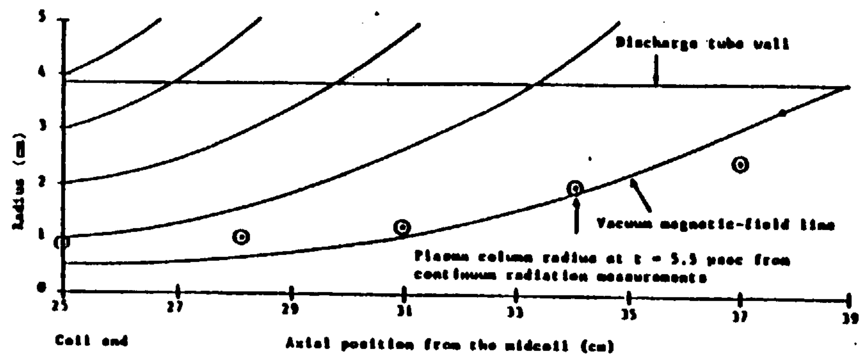

Figure 1

Vacuum Magnetic-Field Line Configuration in the End Region of the Theta Pinch With Experimental Gaussian 1/e Plasma Column Radii Values From Continuum Radiation Data at t = 5.5 μsec

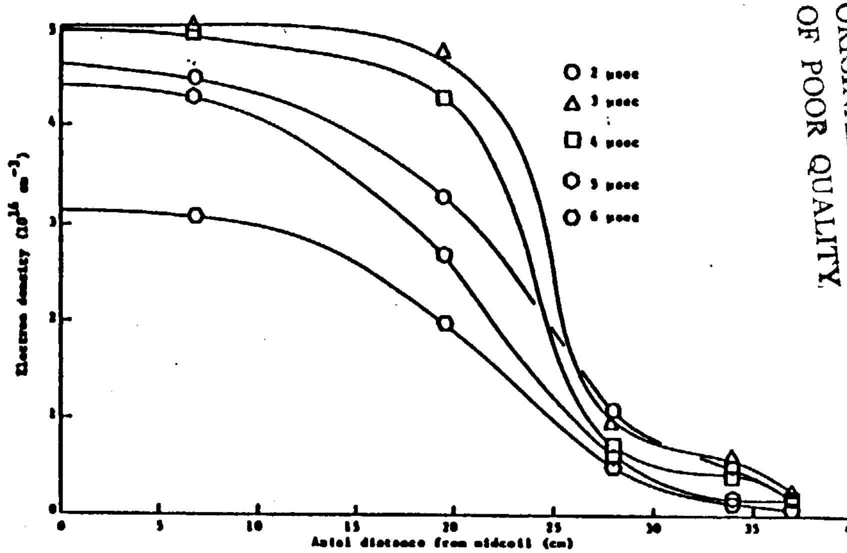

Figure 2 Profiles of Electron Density as a Function of Axial Position for Several Fixed Times During the Discharge. These Were Determined From Thomson Scattering.

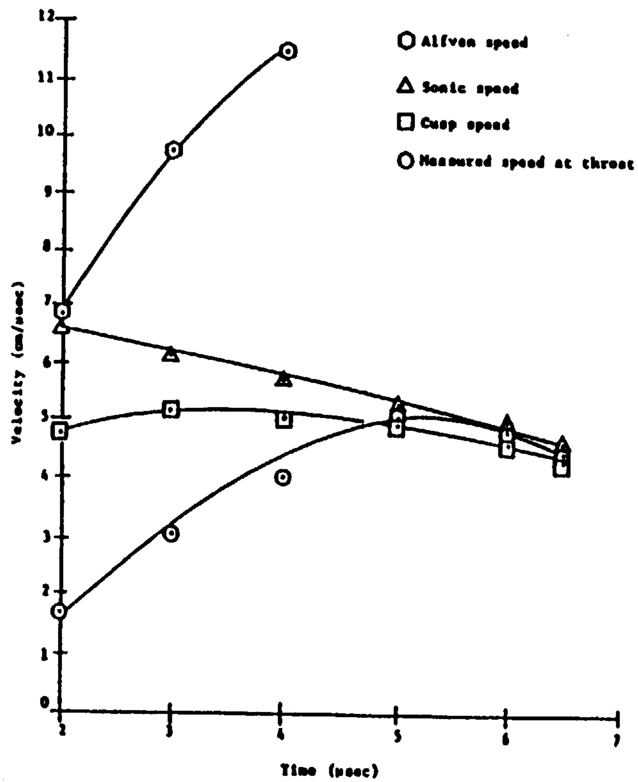

Figure 3 Characteristic Speeds Compared to the Measured Speed at the Throat

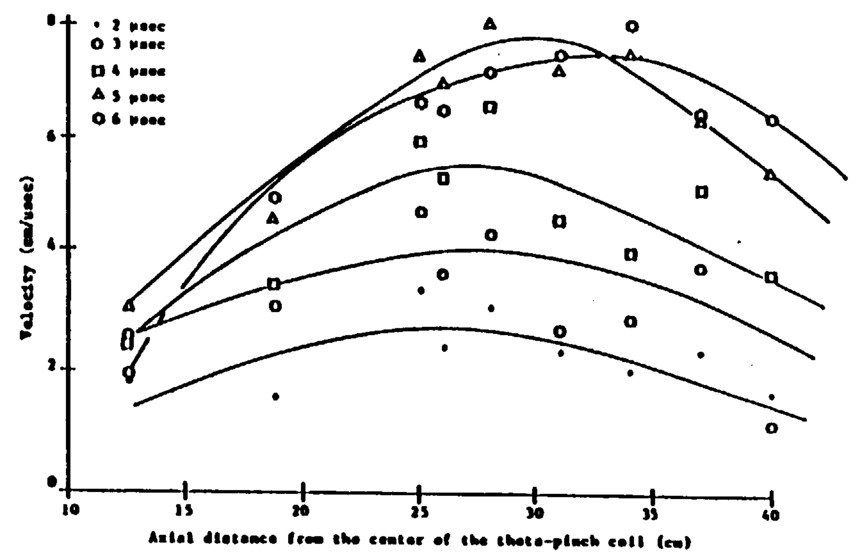

Figure 4 Measured Plasma Velocity as a Function of Axial Position